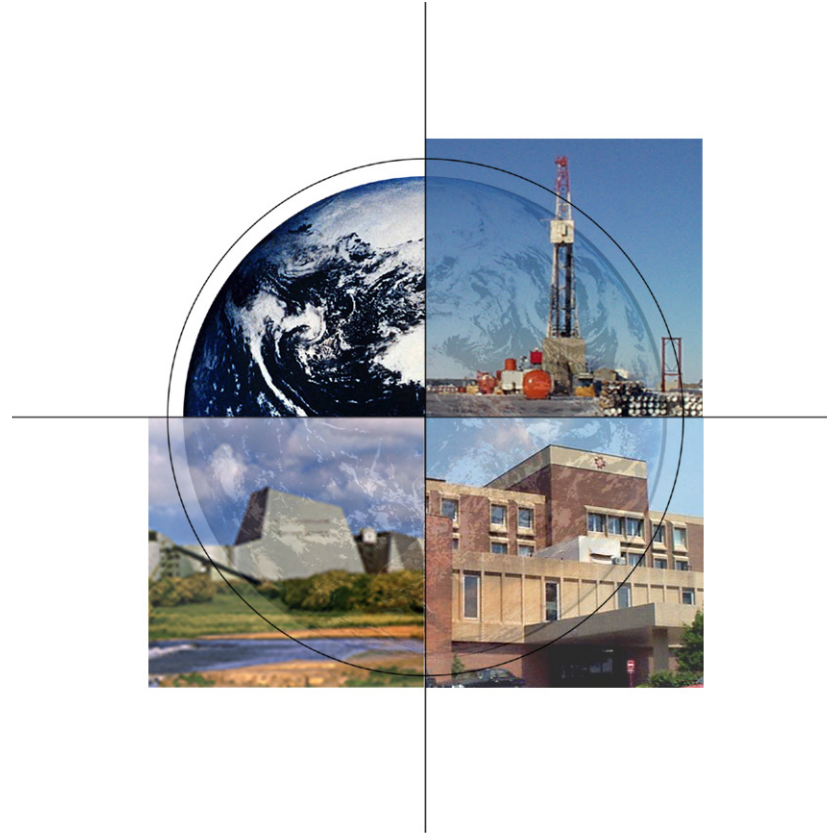


# High Efficiency Engines and Turbines (HEET)



**Abbie W. Layne**  
**National Energy Technology Laboratory**



# Planned Accomplishments -- FY 2002

Siemens - Westinghouse

General Electric Company

## 501GS -- 60 Hz



501G Launch Site  
Lakeland, Florida

**375 MW, 59% Efficiency**

Component Test	2002
Operation	2003

## 7H -- 60 Hz(ATS)



2 x 107H Launch Site  
Scriba, New York, USA

**400 MW, 60% Efficiency**

FSNL Test	2000
Wales 50Hz Operation	09/02
Scriba Operation	2004



# HEET Goals & Objectives

## HEET Goals (By Year 2010)

- Conservation of Fuel (60% HHV efficiency Coal Plants)
- Near Zero Emission Plants (no carbon, negligible NOx and contaminants)
- Operational Flexibility in fuels (coal syngas, H<sub>2</sub> > 400 starts)
- Improved electricity reliability and competitive life cycle cost

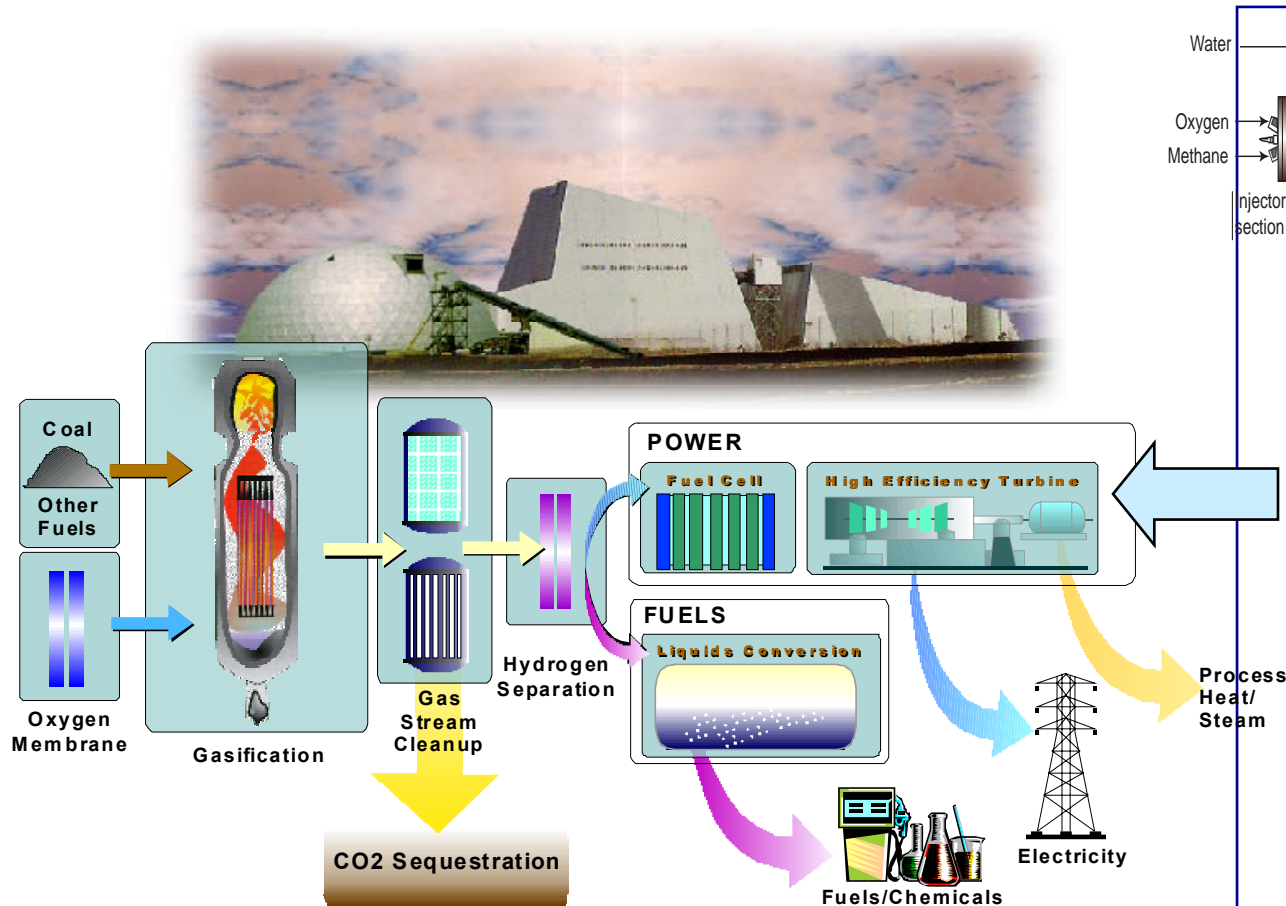


## HEET PRODUCT OBJECTIVES

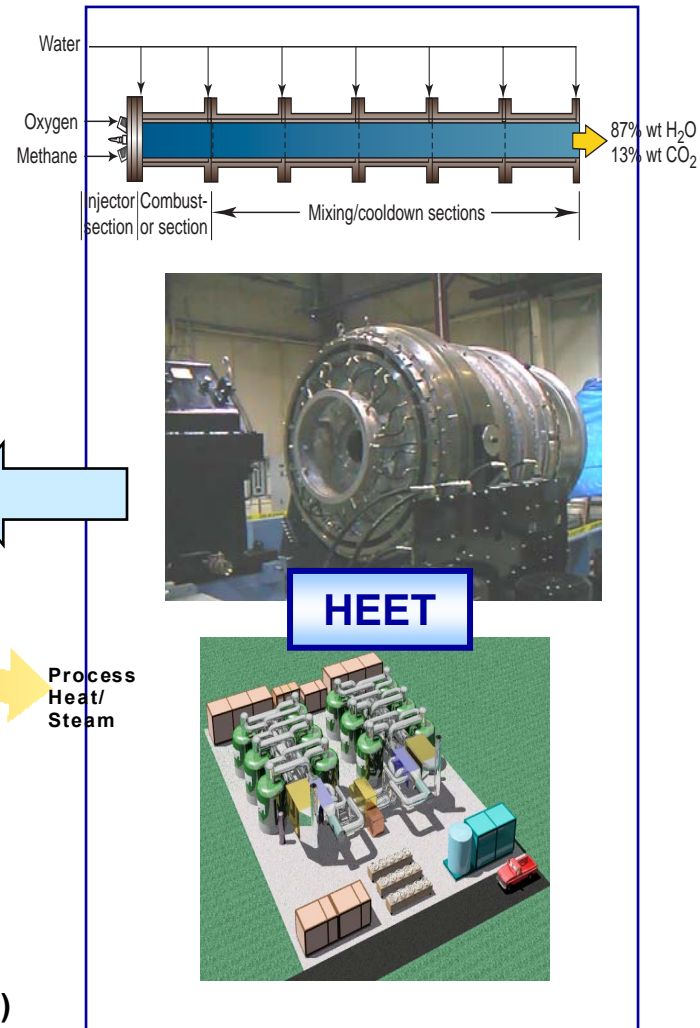
<b>Year 2003</b>	Complete development of advanced technology for improved electricity reliability, reduced emissions, and higher efficiency
<b>Year 2005</b>	Install and demonstrate advanced technology mentioned above Establish designs for advanced industrial and hybrid power systems
<b>Year 2010</b>	Develop fuel cell turbine hybrid cycles (around 70% ) with near zero emission for central and DG applications <b>(Mid term Vision 21)</b>
<b>Year 2010-15</b>	Develop fuel cell turbine hybrids approaching 80% efficiency with near-zero emission applicable to central and DG applications <b>(Long term Vision 21)</b>



# Vision 21 Goals Require HEET Program



**100 - 450 MW Central Power Stations -Near Zero Emission**  
**Electrical Efficiency: 66%HHV (Coal), and 75% LHV (Natural Gas)**



# Pathways to Achieve Clean Coal Goals

## Technology Roadmaps

- Materials
- Combustion
- Aero/thermal
- Controls/Sensors
- Condition Monitoring
- Design Tools

## Advanced Power Plants

- Syngas/Hydrogen combined cycle
- Fuel cell/turbine hybrids
- Rocket engine steam cycle
- Ramjet engine
- Hydraulic compression

*Technology roadmaps utilized for comprehensiveness*





# ATS and HEET Programs are Critical Technologies to:

- Meet High-efficiency, High-reliability Power Plant Generation Performance Requirements
- To Time the Development of Advanced Engine in Synchronization with Energy Legislation Goals

Program	ATS	HEET Mid-term			HEET Long-term	
System Definition	ATS	Flexible Turbine Systems	Fuel-Flexible ATS	Turbine/Fuel Cell Hybrids	Hybrids	Revolutionary Turbine Cycles
Electrical Efficiency (% LHV)	60	15% Improvement over current systems	> 50 (CC)	70	<b>75 - 80</b>	> 65
Power Rating (MW)	400	> 30	> 50	< 30	> 60	> 60
Fuels	Natural Gas	Natural Gas, Coal	Coal	Natural Gas	> 30	> 50
Power Markets	Central Station	Distributed, Central Station	Central Station/Self Generation	Distributed	Vision 21	Vision 21
These systems will be permissible under 2010 regulations - Acceptable life cycle and Cost of electricity (COE)						



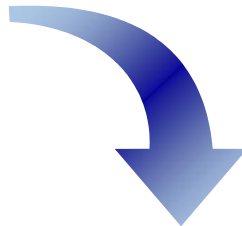
# HEET Development Plan

## H TECHNOLOGY (ATS)



### 2003-2005

- 65% efficient hybrids(<40MW)
- 50% efficient coal turbine plants



### 2010

- 70% efficient hybrids(40MW)
- 52% efficient coal turbine plants

### 2015

- 75% efficient gas plants
- 60+% coal plants
- Propulsion



# Technology Needs of Advanced Power Plants

Advanced Power Plant Type	Technology Needs
Syngas/H <sub>2</sub> Combined Cycle	<ul style="list-style-type: none"><li>• Advanced membranes for H<sub>2</sub> Separation</li><li>• Advanced H<sub>2</sub> transport and storage systems</li></ul>
Rocket Engine Steam Cycle (CES)	<ul style="list-style-type: none"><li>• Ultra-high temperature steam turbines</li><li>• High-efficiency air separation units</li></ul>
Turbo Fuel Cell Hybrid	<ul style="list-style-type: none"><li>• High Temperature fuel cells</li><li>• Membranes for separation of air, H<sub>2</sub> and CO<sub>2</sub></li><li>• Advanced gas turbines</li></ul>
Hydraulic Compression System	<ul style="list-style-type: none"><li>• Advanced air/water induction systems</li><li>• Advanced air/water separation systems</li><li>• Advanced gas turbines and recuperators</li></ul>
<p>Common Technology Needs:</p> <ul style="list-style-type: none"><li>• Improved reliability, availability, and maintainability</li><li>• Advanced sensors, data acquisition and controls</li><li>• Advanced materials</li></ul>	





# Alternative Engine Concepts



- **Ramgen Power Systems Inc.**

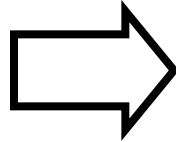
Developing a novel concept based on ramjet technology to spin a wheel and produce power. It has the potential to significantly lower power generating initial and maintenance costs. The Ramgen engine concept can utilize waste fuels (such as coal bed methane) and very lean fuels such as the unutilized fuel in the exhaust of the fuel cell. A pre-prototype can be a component in Vision 21 power plants. Ramgen will test a 10 to 15 MW engine, synchronize with the power grid. After this analysis, It will design a larger engine.

- **Clean Energy Systems**

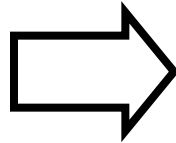
Designing/Testing a 10 MW high temperature gas generator intended for use in a Zero-emission power plant. The gas generator is based on rocket engine technology and burns clean fuel (methane or gaseous fuel, or synthetic fuel). The project was selected in the first group under Vision 21 Program solicitation.

# Vision: Rocket Technology Adapted For Turbine Power

**Rocket Engine  
Technology**



**Clean Energy  
at Low Cost**



## **Zero-Emission Power Plants**

- Low Cost Electric Power
- Easy Plant Siting
- CO<sub>2</sub> for Enhanced Oil Recovery
- Vision 21 Industrial Parks
- Low Cost Hydrogen Production
- Fuel Flexibility(coal, natural gas, biomass, oil)

# Turbine Hybrid Power Plants

- 250Kw-40MW output rating
- Up to 70% electric efficiency(LHV)
- Ultra-low emissions
- Base-load operation
- Currently for niche, high price markets
- Cost reductions targeted for future systems



**Manufacturers: Fuel Cell Energy, Siemens  
Westinghouse**

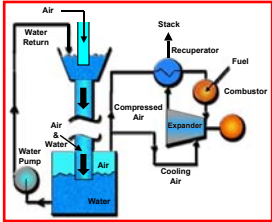



# Development and Testing of a Pre-Prototype Mach 2 Ramgen Engine

- Ramjet thrust modules spin on rotor at supersonic speeds
- Fewer moving parts than IC engine-superior for syngas operation/less exposed hot gas path parts
- High part load efficiency
- Low emissions(<4ppm NO<sub>x</sub>)
- Testing program ongoing with the DOE Office of Fossil Energy(NETL) for 800KW to 40 MW systems
- 1st demonstration at coal mine sites



# DOE HEET Accomplishments

HEET Portfolio Elements	Projects
<p><b>Advanced System Analysis</b></p> 	<p>System Analysis of promising concepts completed:</p> <ul style="list-style-type: none"> <li>• Syngas/H<sub>2</sub> Combined Cycle</li> <li>• Rocket Engine Steam Cycle (CES)</li> <li>• Turbo Fuel Cell Hybrid (Vision 2020)</li> <li>• Hydraulic Compression (Vision 2020)</li> <li>• 4 NG concept feasibility, technical assessment, and market studies (Rolls Royce, GE, Siemens-Westinghouse, and Pratt &amp; Whitney)</li> </ul>
<p><b>Simple/Combined Cycle Development</b></p> 	<ul style="list-style-type: none"> <li>• Fabrication and complete testing of 100kW igniter and gas generator (CES)</li> <li>• Development and testing of a pre-prototype Mach 2 Ramgen Engine – Complete design of 40 MW engine and begin engine fabrication (Global Power Systems)</li> <li>• Small turbo-generator technology for DG (Rolls Royce)</li> <li>• Gas turbine reheat using in-situ combustion (S-W)</li> <li>• Vision 21 Computational Workbench (Reaction Engineering International)</li> <li>• LES Software for combustion design (CFD Research)</li> </ul>

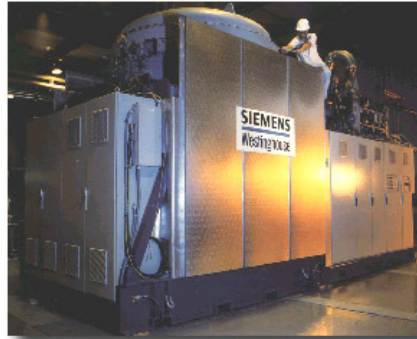
HEET Portfolio: 1) Advanced System Analysis, 2) Simple/Combined Cycle Development, 3) Hybrid Cycle Development, and 4) Technology Base Development





# HEET Development Plan

## Hybrid Cycles Section



### 2003-2005

- 65% efficient hybrids(<40MW)
- 50% efficient coal turbine plants

### 2010

- 70% efficient hybrids(40MW)
- 55% efficient coal turbine plants

### 2015

- 75% efficient gas plants
- 60+% coal plants
- Propulsion



# HEET Program - Hybrid Cycles

## DOE STRATEGY

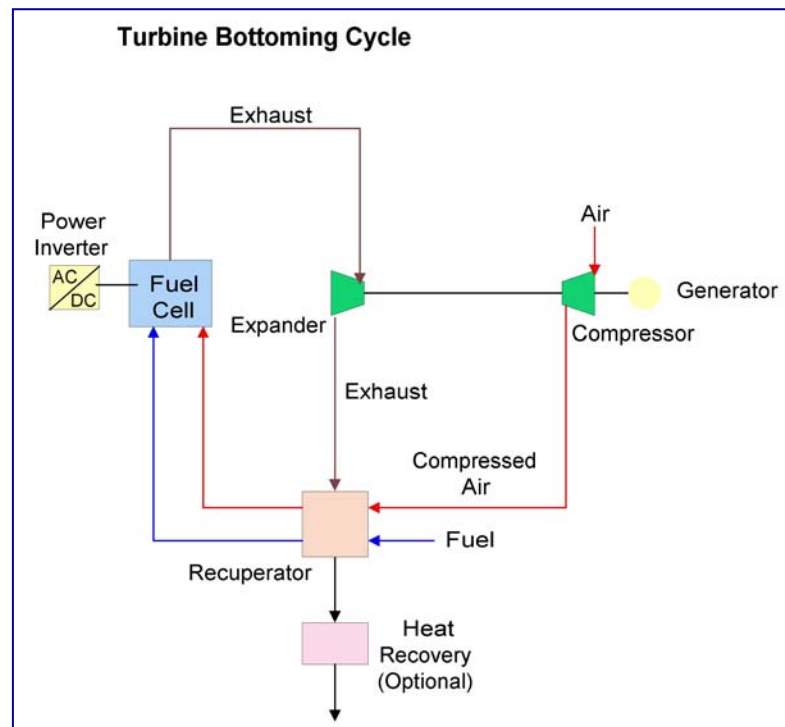
- Turbine Technology to support DOE SECA fuel cells program -Target of SECA hybrid fuel cell turbine systems at \$400/kW
- HEET program seeks development of miniturbines (from about 500 kW to tens of megawatts) because of potential to be applicable for use in \$400/kW hybrid systems, and of its market potential as stand-alone units or as hybrids
- Strategy of HEET is to study integration of fuel cell and turbine, using microturbines, until availability of larger fuel cells
- With large fuel cells available, HEET program will shift to evaluate miniturbine technology base ( 1 to 5MW size range or possibly larger) for MW class hybrid cycles and for use in Vision 21 applications(possibly as 30 to 40 MW modules)
- Nominal 100 MW plants could be envisioned from these 30 to 40 MW modules
- DOE assessments underway to evaluate potential of hybrids at size larger than 40 MW , up to 300 MW capacity



# HEET Program - Hybrid Cycles

## DOE STRATEGY

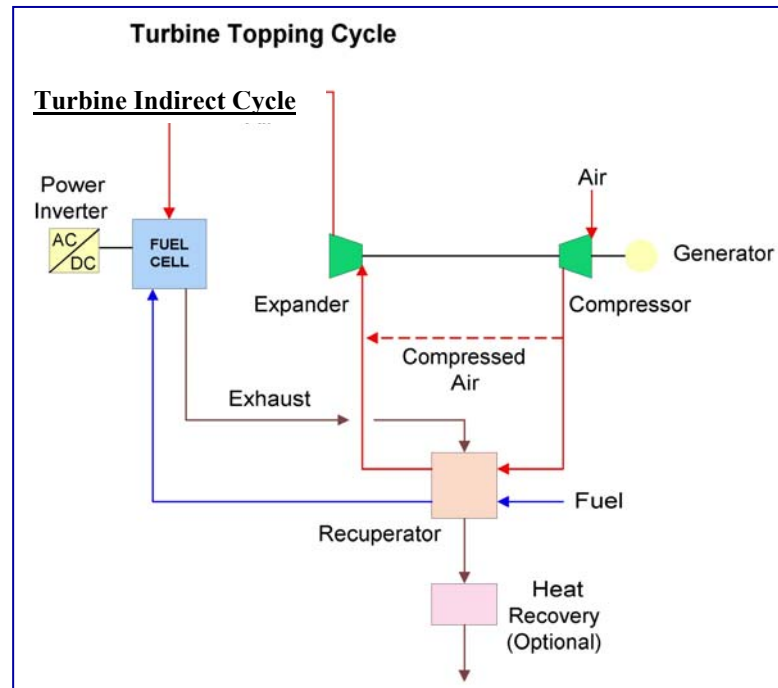
- Evaluations of hybrid system based on 2 concepts defined by the position of the turbine within the cycle
  - Arrangement No.1: Turbine bottoming cycles, e.g. fuel cell exhaust expanded in the gas turbine



# HEET Program - Hybrid Cycles

## DOE STRATEGY

- Evaluations of hybrid system based on 2 concepts defined by the position of the turbine within the cycle
  - Arrangement No.2: Indirect turbine cycles, e.g. fuel exhaust heats an unfired gas turbine



- Both configurations could achieve fuel-to-electricity efficiencies of 58 to 72% and possibly as high as 80% with steam cycle, or multi-reheat turbine.

# Technology Edge of Hybrid Cycles

- **High Temperature fuel Cells (SOFC and MCFC) as most promising fuel cells for power generation - Exhaust converted into electrical energy in a gas turbine or in a combined cycle (gas turbine and steam turbine)**  
**Improvement of the characteristics of fuel cell operating in pressurized mode**
- **Several methods to recover the energy at the exhaust of the fuel cell acting as the combustor of the gas turbine**
  - **Outlet gases of fuel cell expansion in a gas turbine (expander)**
  - **From the gas turbine exhaust to a recuperator**
  - **Inlet air and fuel heated**
  - **Steam generated in the Heat Recovery Unit (HRU) for fuel reforming**
- **Power split between fuel cell and heat engine 70/30 in terms of %**
- **Efficiency of hybrids increased to 70% by increasing efficiency of fuel cell and gas turbine - from current level of development expected at 65%**
- **With the advent of fuel cells capable of operating at higher pressure (from 4 to 9 pressure ratio), consider intercooling of the air when compressing it in a compressor**



# DOE Hybrid 5 Cycles Studies

Company	Fuel Cell Energy	Siemens Westinghouse	Siemens Westinghouse	MC-Power	McDermott
Cycle Configuration	MCFC Indirect	SOFC Turbine Bottoming	Staged SOFC Turbine	MCFC Turbine Bottoming	SOFC Indirect
Nominal Size	20 MW	20 MW	20 MW	20 MW	750 kW
Nominal Efficiency* (LHV CH <sub>4</sub> )	71%	60%	67-70%	66-70%	71%

\* : Nominal efficiencies (based on natural gas) and not to be directly compared



# DOE Hybrid 5 Cycles Studies

## Technical Issues

- **Sub-MW Modules**

- Modify gas path to take into consideration energy flow from fuel cells of direct, and indirect hybrid cycles
- Modify software of turbine control (speed, inlet temperature, surge and trip)
- Redesign turbine for increased thrust loads, and modify turbine casing
- Develop HT heat exchanger for pressurized SOFC system (cathode air inlet heated to 700 degrees C with fuel cell exhaust at 815 degrees C)

- **20-40 MW Modules**

- Protect hybrid system by new control logic and advanced sensor
- Develop anode exhaust oxidizer(catalytic combustor) for large indirect atmospheric pressure hybrids
- Consider that for these sizes, turbines not available without modifications

Consider requirements of Balance of Plant (BOP) such as HT heat exchanger, surge issues in case of direct hybrid cycles, appropriate sensors and HT control and shutoff valves at critical locations of cycle, as well as development of control strategies and methodologies, and fully integrated power conditioning devices

